

WHAT EFFECT DOES THE WARNING OF REACTIONS HAVE ON
THE REACTION TIME

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Vorankündigung von Reaktionen auf die
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16. Abstract Complex reaction time experiments were done with information signals indicating which reaction would be required in choice experiments. Reaction times decreased with increasing interval between information and starting signals, but were never shorter than reaction times in simple reaction time experiments. Longer exposure of the information signal gave longer reaction time. In other experiments in which interruption signals were given simultaneously with the start signals, reaction times were shorter when reactions occurred in spite of the interruption signal. Without the signal, times were longer because subjects waited for the interruption signal.			
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WHAT EFFECT DOES THE WARNING OF REACTIONS HAVE ON
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The concern with reaction times is mostly based on the belief of present authors that in the model of the classical reaction experiment they have optimum conditions for study of those factors which are decisive for starting, performance and ending of simple actions. In spite of the multiplicity and manifold nature of the works which have appeared lately, a "qualitative" analysis has found too little attention. To be sure, the extent to which many factors influence reaction time is known. Yet ideas on what happens, in detail, during the period between the command to act and the beginning of the action have been only insufficiently concretized.

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A direct access to this problem was attempted in the works of Leppin & Eriksen (1966) and of Amelang (1967), where the events, which connect the signals and responses in reaction experiments, were intended to be made "visible", as it were, so that the action just started would have to be suppressed or interrupted.

Merz (1971) has recently followed another route. He reports on two series of experiments in which the test subjects were forewarned of the required choice reaction through corresponding

* Numbers in the margin indicate pagination in the original foreign text.

signals which preceded the actual initiating signals by a period of varying length. The central finding was that the reaction times decreased with increasing time separation of the warning or information signal ahead of the reaction signal. With appropriate warning at the right time, then -- the longest interval used was 1.0 second -- it is possible to eliminate at least part of the information processing which provides identification of the signal currently present and the preparation and initiation of the reaction assigned to it.

Without question, this observation has direct relevance for practical interests, to which Merz has already referred with examples from traffic, work and sports. Not only for this reason, but also with respect to the theoretical implications for the question raised above, detailed concern with warning of simple motor actions is indicated. This is also the case because in the above-mentioned work by Merz, some results contradict each other, while certain questions have been raised, or remain completely unanswered. We shall next consider these briefly.

Statement of the Problem and Hypotheses

The basic thesis of Merz, which we also accept, states that the "increase in the reaction time" which occurs with an increasing amount of information "can be eliminated if the test subject is at the proper time given a signal of what he must do, so that the necessary process of deciding on the nature of the reaction is terminated before the time of the reaction is established . . ." and ". . . under these circumstances a choice reaction changes into a simple reaction." (Merz, 1971, p. 630).

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In agreement with that, the maximum shortening of the reaction time by warning was greater for multiple choice (168 msec shortening, comparison intervals 0.0 and 0.6 sec) than for a two-fold choice, where the difference was only 104 msec (comparison intervals 0.0 and 0.4 sec)¹.

Still, even with the optimum warning intervals of 0.6 and 0.8 or 0.4 seconds there was still a (significant?) difference between four-fold and two-fold choice in favor of the latter (542 as compared to 509 msec). This is not compatible with the postulated reduction of four-fold or two-fold choice reaction to simple reactions in the same manner. (unless the questionable difference is a result of the circumstance that each individual one of the four-fold reactions was performed only 15 times in the course of the experiment, while the alternatives in the two-fold choices were performed 60 times, as the total experiment provided only half as many four-fold as two-fold selections!)

For still another reason, we must doubt the existence of simple reactions at intervals equal to or greater than 0.4 sec.: Even the shortest reaction times, with average durations of 509 and 542 msec are far above those usually determined in simple reaction experiments, 150-250 msec (see Woodworth & Schlosberg, 1960, 8-42).

¹ Similar observations were also made for complex movements as compared to simple ones, but this variable will be ignored here for two reasons: (1) the differences between the relatively easy and difficult movements were numerically small and barely statistically significant; (2) in our opinion, the factors causing these differences can in all cases be equated with part of those which produce longer reaction times as a result of increased uncertainty about the event.

If we seek a common cause for the generally increased reaction times for both unaffected and warned reactions, the following explanation offers itself: The situation of warning of a definite reaction required later in a choice experiment accelerates the performance of this reaction, but there is a possibility of encountering some decisions first. But the warning itself presents a problem for which additional capacities are required. The current signal must be preceived, and correct reaction must be selected, and its performance must be induced. All this leads to an additional load on the "central channel", resulting in a general increase in the reaction times. These could, to be sure, become less with increasing warning intervals, because the program ready for a problem is more and more completed. Demonstration of such a liberation of capacities for the additional problem of processing the warning signal can be done only by comparing reactions warned with an interval of 0.0 seconds or, taking into consideration the occurrence of a "psychological refractory phase" (see Smith, 1968), somewhat longer, with reactions occurring under conditions without warnings. Then, in the sense of the preceding discussion, we must expect (Hypothesis 1) that reaction times for reactions with brief warning intervals will be greater than those without warning. / 4

Then, by performing conventional simple reaction experiments under other wise identical conditions (without warning), we can test whether the reaction times observed with choice experiments at optimal warning intervals correspond to those of the simple reaction experiment. Here, according to the views initially cited, only random differences should occur between the reaction times of simple and long-forewarned choice reactions. But we must also consider the following: For every warning interval other than zero, the information contained in the warning signal must also be stored before it is processed. The storage room required for recording it, or the channel capacity needed

for it, increases with the complexity of the reaction experiment. Therefore, (Hypothesis 2) we must expect the reaction time for warned reactions to rise with the number of possible choices, even with optimal warning for the reaction.

The behavior of the warning information, which is perhaps a reason for the discrepancy which Merz found between the empirical and expected values in the range of 0.4 to 1.0 second interval, presumably plays a less important part if the warning signal is present from the time of its exposure until the appearance of the reaction signal, than if it is presented only briefly. Thus, (Hypothesis 3) we expect the reaction times to be reduced more with longer duration of exposure for the warning signal.

One last point of view, finally, applies to Merz's experiments with longer warning intervals, where the reaction times increased again. This cannot be brought into agreement with the concept of change from choice to simple reactions at all. Here there are certain parallels with an experiment of Mowrer (1940). There, in a simple reaction experiment, signals were answered particularly slowly if they appeared before or after the passage of an average interval in connection with the general "attention" signal. Mowrer ascribed this to the time relations between the preliminary and the main signal being learned in the course of the experiments, and strategies being developed to predict the critical signal. If the critical signal appears randomly, sometimes earlier and sometimes later, it is optimal to be most ready for average intervals. Corresponding to this concept, (Hypothesis 4) the curve of the reaction times versus the individual intervals must be generally lower² and flatter for systematic succession of the warning intervals than with random sequence for the intervals.

² This statement, admittedly, was somewhat limited by certain details of the experimental arrangement; See Methods, II, next to last section.

Methods

I. General

In a reaction experiment, an auxiliary signal was exposed before the actual starting signal. The auxiliary signal contained the information on which of the available signals would appear later. The variables were:

- A) The length of the interval (VI) by which the warning or information signal preceded the actual reaction signal (1, 16, 32, 64 and 128 hundredths of a second);
- B) The complexity of the reaction experiment (simple reaction experiment, two-fold and four-fold choice);
- C) The duration of exposure of the information signal (16 and 256 hundredths of a second);
- D) The sequence of the warning intervals from reaction to reaction (systematic and random).

Factors A to D were realized in the form of a complete, complex plan of variance analysis with measurement repetition over all combinations of conditions (each test subject was studied under all conditions). It was also established

- E) With which finger the individual reactions were performed (1 to 4, corresponding to the index finger to the little finger).

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Experiments were also done as control without warning.

II. Permutation Plan

The complete experiment is organized in two parts which were performed separately. Their sequence was systematically varied from one subject to another. In one part, the sequence to

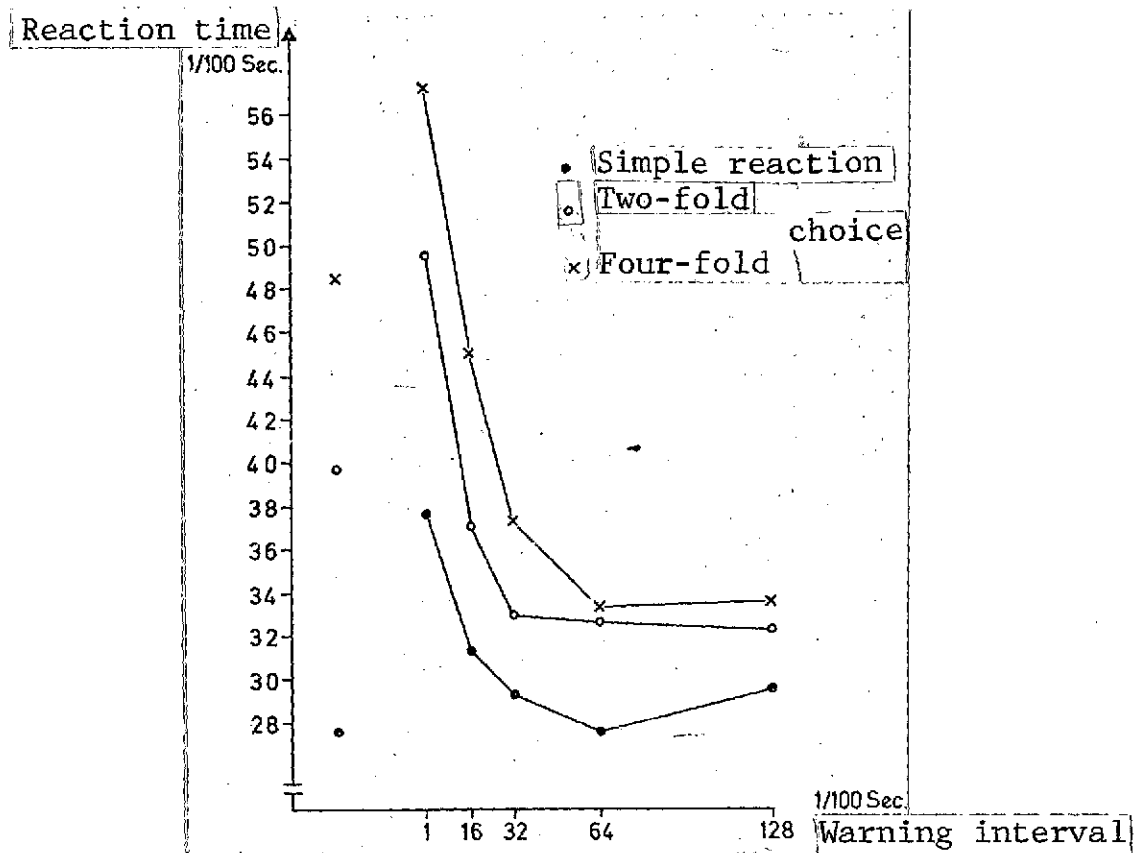


Figure 1a. Mean reaction times (in hundredths of a second) for simple, twofold and fourfold choice as functions of the length of the warning interval. Averaging over the different exposure durations of the information signals. Random sequence of warning intervals. The values marked separately directly beside the ordinate indicate the results of the control experiments.

of warning intervals was systematically increasing or decreasing (1 - 16 - 32 - 64 - 128 or 128 - 64 - 32 - 16 - 1). In the other part the sequence of warning intervals was random. / 7

The steps in complexity of the reaction were always prescribed in blocks within each of these experiments. The sequence of simple, two-fold and four-fold choice experiments also changed systematically between the test subjects in order to

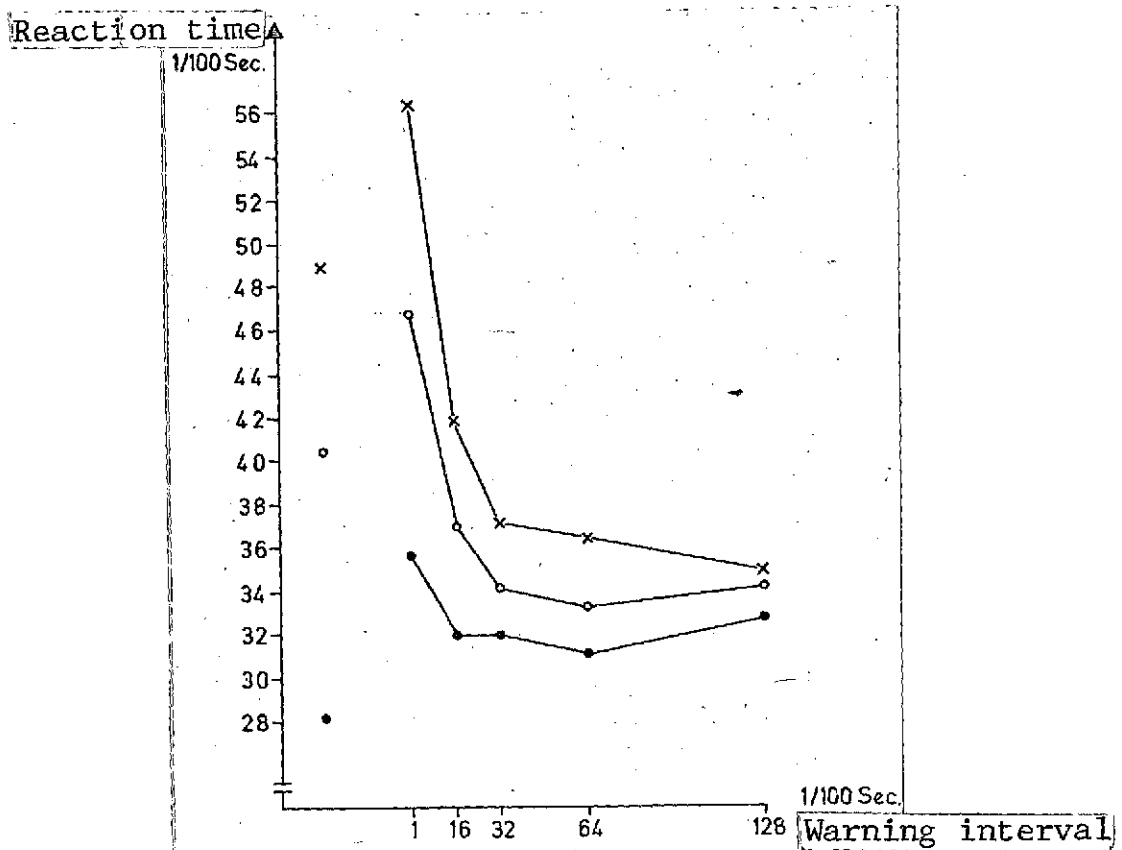


Figure 1b. Like 1a, but with systematic sequence of warning intervals.

avoid any possible effect of practice between the conditions.

The duration of presentation of the warning signal varied randomly within the individual stages of Factor B (number of possible choices).

The control experiments were performed in blocks both before and after the realization of each stage of Factor B. In all, there were twelve such blocks, with three stages in difficulty of the reaction and two for the sequence of the

warning intervals.

For each field of the experimental plan it was established that the four fingers of one hand (without thumbs) were used equally frequently as reaction elements with simple, two-fold and four-fold choice. This was done with a method which has already been used in another connection, and is described there (see Amelang, 1971).

With the systematic sequence of warning intervals, one "trap experiment" was always given with one of six stimulus presentations (that is, 5 warning intervals plus one additional reaction). In the trap experiment, a warning signal was given, but no actual starting signal was given. These trap experiments appeared in random sequence between the other experiments. They were inserted to ensure that the test subject always reacted only to the start signal, because, with the systematic series it is possible for the subject to estimate the duration of the interval after a few experiments. Under these conditions, the person could react to the warning signal with an appropriate delay.

There were no such trap experiments with the random sequence. Here, the irregular succession of the warning signals largely prevented a strategy in the sense mentioned above. With their potential appearance, also, the interval of 128 could have been kept for a trap experiment. In this way, the readiness for reaction would presumably have been reduced by the experiments with relatively long warning intervals with the result of artificially increased reaction times in those cases where the actual start signal was still exposed.

III. Reaction Objectives, Test Subjects, Etc.

Four small lamps, arranged in a semicircle corresponding to the four fingers of the right hand (or the left hand, if the test subject preferred) served as starting signals. Reaction pushbuttons were arranged conveniently in a semicircle. The time from lighting of one of these lamps until the matching button was pressed was measured with an electronic stopwatch. False reactions, which could be identified as such by the test conductor by means of corresponding control lamps, were repeated at the end of the experiment ³.

Twelve students, in different semesters of psychology and of both sexes, participated in the experiment on a voluntary basis. The values for one of the subjects were eliminated before the accounting was made, so that the number of random samples decreased to $N = 11$.

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Results ⁴

All the individual reaction times were transformed into their reciprocals before further computation. This was done to eliminate the skewed distribution which commonly occurs in such measurements.

Figures 1a and 1b show the reaction times, averaged over both stages of exposure duration for the information signal. The differences with respect to the warning intervals are in all cases significant at the one part per thousand level (three

³ We thank Mr. Bussacker for the painstaking development of the apparatus.

⁴ We thank Dipl.-Psych. Christian Frey, Hamburg, for his help in the extensive calculations, and Dr. J. Wandmacher, Constance, for providing a computer program.

four-fold variance analyses, see Table 1), so that the findings of Merz are confirmed.

Furthermore, and this is important for Hypothesis 1, the mean reaction times for the unwarned reaction times differ with high significance from those reactions warned with a 10 msec interval. In the variance analyses performed separately for the four potential combinations of the factor stages of C and D (exposure duration for the warning interval signal; sequence) with the factors A (with or without warning, where all the control reactions, i. e., those done before and after the trials with warning were combined under the condition "without"), B (complexity of the reaction experiment) and E (finger), the probable error for the corresponding differences in averages was always less than 1%. Aside from the main effect for the complexity of the reaction (B), which was significant in all cases, the interaction between A and B was always surprising. The extension of the reaction time for reactions with very brief warning, as compared to the control experiments, decreases with the number of possible choices.

On the basis of this result, Hypothesis 1 could be considered to be verified. In further agreement with this is the observation that in simple reactions it is practically only the reaction times of the reactions warned at the intervals of 64 and 128 which decrease to the level of the uninfluenced reactions. But for all other intervals, the warning not only produces no further shortening (which would not be expected even by the "general" hypothesis), but leads to an extension, because to all appearances the consideration of the warning information is a problem in itself, with the corresponding consequences.

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The basic results for testing of Hypothesis 2 are shown in Figure 2, separately for the intervals 64 and 128, as both

Table 1.* RESULTS OF THE 4 x 5 x 2 x 2 VARIANCE ANALYSES, PERFORMED SEPARATELY FOR SIMPLE, TWO-FOLD AND FOUR-FOLD SELECTION, WITH DUPLICATION OF MEASUREMENTS ON ALL FACTORS.

Source of Variation	df	Simple Reaction			Twofold Reaction			Fourfold Reaction		
		MS	F	P	MS	F	P	MS	F	P
Test subject (S)	10	44.531,92			45.488,89			32.573,77		
Finger (Fin)	3	17.895,45	4,88	< 0,05	48.224,16	9,12	< 0,01	11.177,89	2,66	(< 0,1)
Fin x S	30	3.660,13			5.285,29			4.192,96		
Warning interval (VI)	4	131.086,87	19,78	< 0,01	303.427,93	43,19	< 0,01	413.147,93	56,46	< 0,01
VI x S	40	6.628,58			7.025,33			7.317,83		
VI x Fin	12	2.850,41	1,21		5.299,63	1,79	(< 0,1)	5.197,43	1,62	(< 0,1)
VI x Fin x S	120	2.350,31			2.954,36			3.210,56		
Sequence (Seq)	1	66.277,01	28,81	< 0,01	34.300,04	6,45	< 0,05	17.488,56	9,88	< 0,05
Seq x S	10	2.300,11			5.319,47			1.770,51		
Seq x Fin	3	4.024,46	2,87	(< 0,1)	3.651,36	1,69		1.590,76	< 1	
Seq x Fin x S	30	1.404,27			2.155,33			2.731,40		
Seq x VI	4	5.274,31	1,76		14.549,25	6,13	< 0,01	1.552,72	< 1	
Seq x VI x S	40	2.992,83			2.373,98			2.651,82		
Seq x VI x Fin	12	2.079,10	< 1		2.450,95	< 1		3.147,08	1,32	
Seq x VI x Fin X S	120	2.956,26			2.483,37			2.386,62		

*Commas in numbers represent decimal points.

Duration of presentation (DP)	1	69.509,14	5,87	< 0,01	5.824,65	< 1	51,56	< 1
DP x S	10	11.850,30			9.515,90		15.989,65	
DP x Fin	3	559,79	< 1		984,90	< 1	4.615,21	3,19 < 0,05
DP x Fin x S	30	3.039,88			2.618,44		1.444,97	
DP x VI	4	22.050,67	6,33	< 0,01	3.448,36	< 1	9.629,39	2,36 (< 0,1)
DP x VI x S	40	3.483,28			3.751,04		4.071,63	
DP x VI x Fin	12	3.328,53	1,48		3.801,22	1,47	3.393,19	1,31
DP x VI x Fin x S	120	2.237,55			2.579,43		2.582,99	
<hr/>								
DP x Seq	1	5,73	< 1		41,02	< 1	2.740,69	< 1
DP x Seq x S	10	1.684,60			2.442,24		8.149,83	
DP x Seq x Fin	3	2.038,45	< 1		6.259,24	3,44 < 0,05	1.704,46	1,33
DP x Seq x Fin x S	30	2.167,66			1.819,32		1.278,66	
DP x Seq x VI	4	758,79	< 1		2.964,61	1,33	1.579,91	< 1
DP x Seq x VI x S	40	2.983,50			2.236,59		2.953,06	
DP x Seq x VI x Fin	12	1.571,99	< 1		2.967,82	1,44	1.866,66	< 1
DP x Seq x VI x Fin x S	120	2.367,65			2.058,96		2.185,75	
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Total	879							

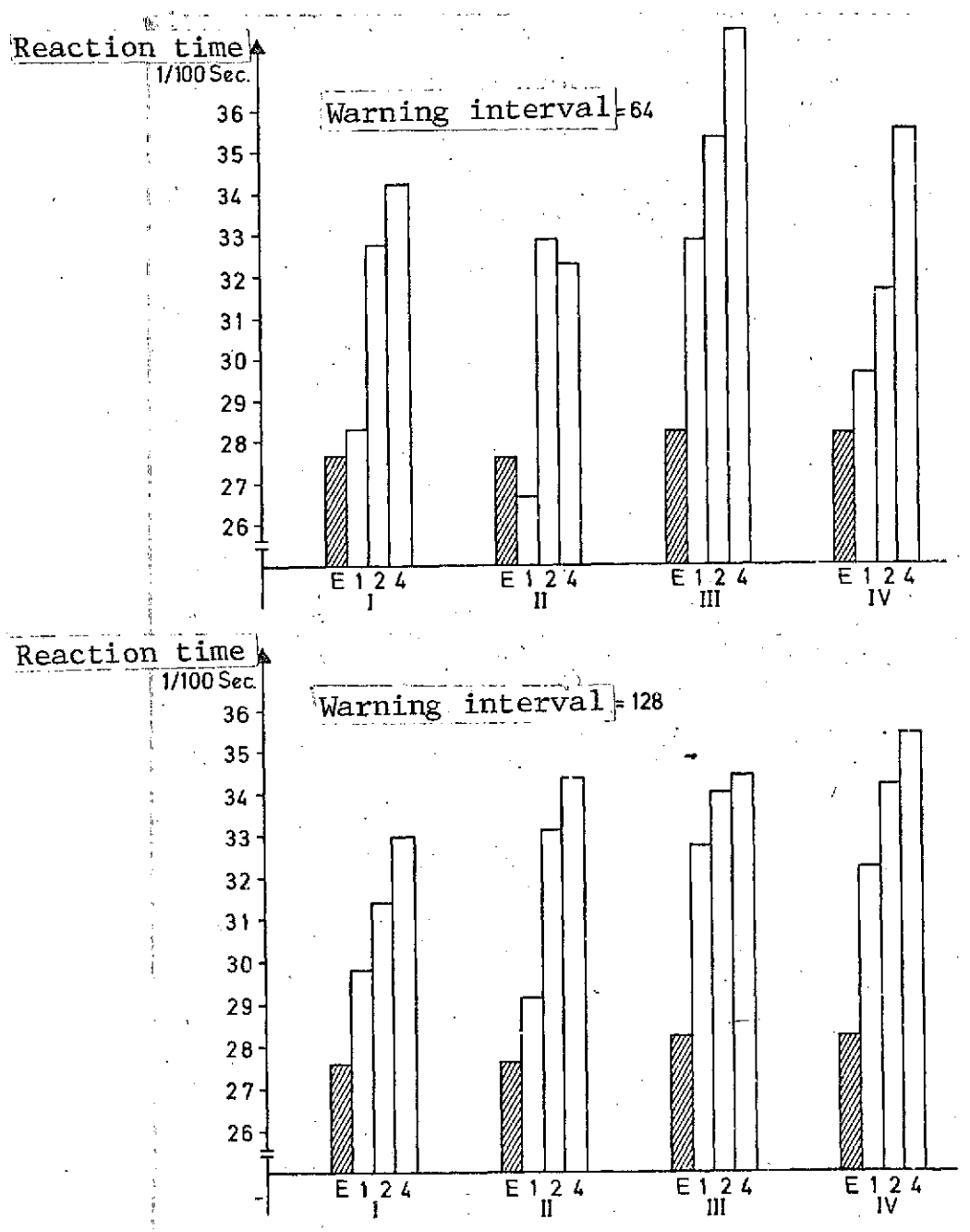


Figure 2. Average reaction times (in hundredths of seconds) for the simple control experiment (E) and the reactions with warning intervals of 64 and 128 in simple reactions (1), two-fold (2) and four-fold (4) choice, separately presented for the combinations of duration of presentation for the warning signal and the sequence of warning intervals. I: long presentation, random sequence; II: short presentation, random sequence; III: long duration, systematic sequence; IV: short duration, systematic sequence.

were about equally optimal.

As can be seen, the reaction times of the warned reactions rise monotonically with the number of potential choices, with one exception. Corresponding with the blocks I to IV in Figure 2, four two-fold variance analyses were calculated with the factors "complexity of reaction" (4 steps, 3 degrees of complexity and the simple control experiment) and "Finger" (E). The factor of interest here, "complexity", was significant to at least the 1% level in all cases. Orthogonal comparison done in connection with these analyses showed that the differences were due primarily to the difference in the reaction times for two-fold and four-fold choice as compared to the control values (exceptions: interval 128, block III; here, too, the difference from the two simple reaction experiments was significant.)

Thus, the view of Merz, according to which a choice reaction is changed to a simple reaction by warning, must be rejected in favor of our Hypothesis 2, which makes somewhat differentiated statements on this point.

For further confirmation of Hypothesis 2, the values shown in Figure 2 were recalculated without the control values presented with them there. Separate variance analyses were done for the intervals 64 and 128 as well as for both stages of Factor D (sequence) (Complexity, exposure duration, finger). The only factor of importance for this question is "complexity". It showed (1%) significance in three of the four cases. The critical F value was missed by only a little for the interval 128 with systematic sequence for the trials for 2 and 20 degrees of freedom. But here, as in the other cases, the averages are in the expected direction, so these results, in all, also favor Hypothesis 2.

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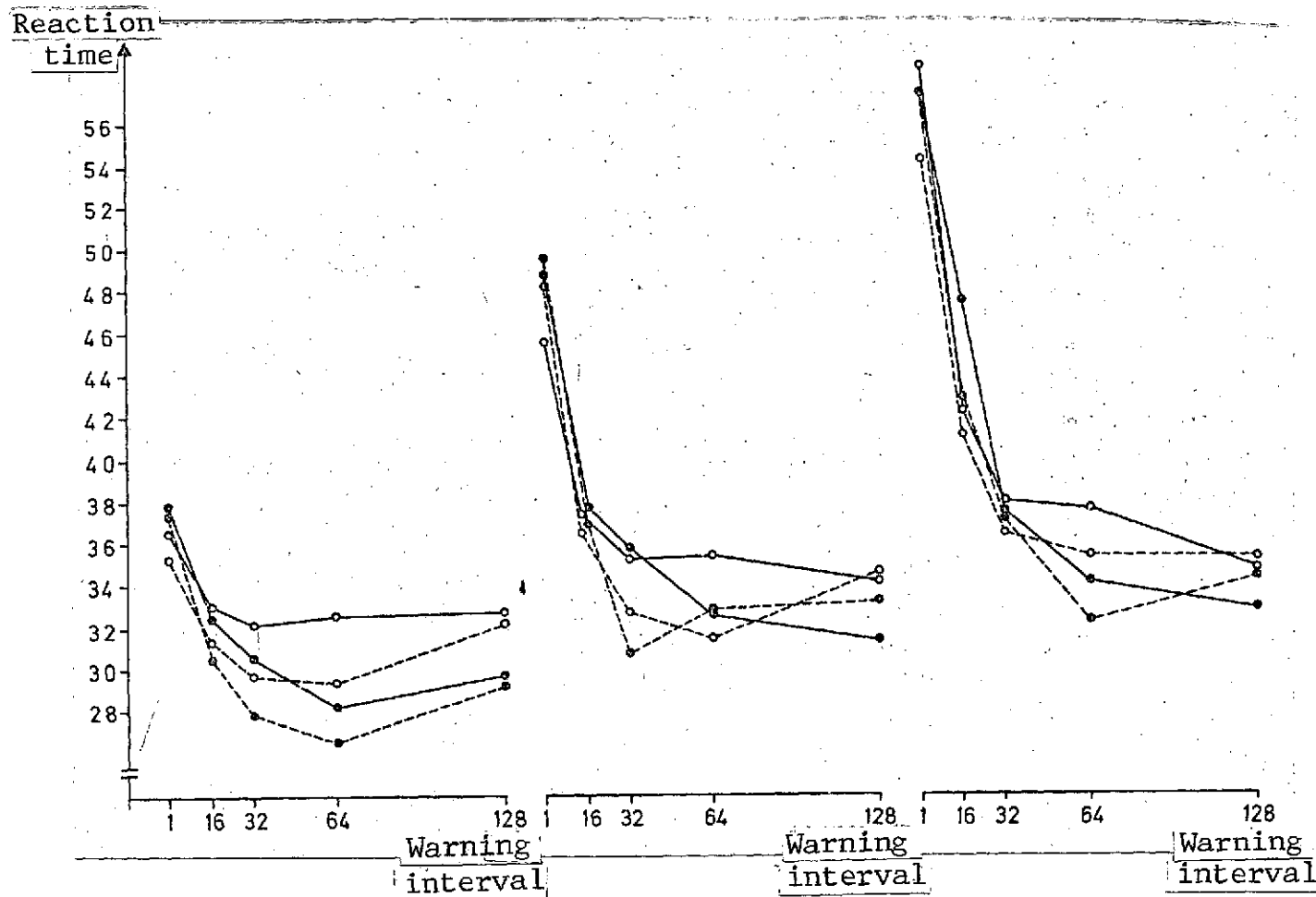


Figure 3: Mean reaction times (in hundredths of a second) with long and short exposure of the information signal as functions of the length of the warning interval, separated in each case for the simple reaction (a), two-fold (b) and four-fold (c) choice, and for random and systematic sequence of the warning intervals.

- — ● long exposure, random sequence
- - - - ● short exposure, random sequence
- — ○ long exposure, systematic sequence
- - - - ○ short exposure, systematic sequence

With respect to Hypothesis 3, the reaction times for simple, two-fold and four-fold choice are shown separately in Figures 3a-c for the different exposure periods of the information signal. At all conditions, there is a difference in favor of the shorter exposure duration. This directly contradicts the hypothesis initially formulated. To be sure, the effect mentioned can be confirmed in detail statistically only in the simple reaction (see Table 1, $F = 5.87$, $p \leq 0.01$).

Furthermore, we can see that the positive effects from [a] briefer presentation of the information signal appear particularly distinctly with medium-length warning intervals. The corresponding interaction $A \times C$ (Length of the warning interval \times duration of exposure), however, attains statistical significance only in the case of the simple reaction (see Table 1).

For testing Hypothesis 4, we are primarily interested in the interaction of Factors A (warning interval) and D (sequence of warning intervals). The principal effect in D favoring the systematic sequence (see Table 1, sequence of the intervals significant at all three stages of complexity) cannot be interpreted, because trap experiments were performed between the individual starting stimuli only in this condition. This lengthened the reaction time somewhat beyond what the "foresight"

of the subject would have produced. As already mentioned, the trap experiments were important, though, because otherwise the subjects might have reacted primarily to the information signal (with appropriate delay).

The averages presented in Figure 3 show how, with systematic sequence of the warning intervals, the functions of the reaction times begin relatively low at short warning intervals, decrease less strongly through the moderate ones, and then at longer intervals, do not rise so steeply (if at all) as the reaction times with random sequence.

The corresponding interaction A x D (interval length x sequence of the intervals) turns out to be non-random in the four-fold analysis (see Table 1) only for the two-fold selection, however. In detail, the effect is apparently expressed more strongly with a longer exposure duration of the information signal than with a shorter one. According to three-fold analyses done separately for the individual stages of the reaction complexity and exposure duration there were significant interactions in the expected direction with long duration of exposure but not with short duration. Thus, part of the observations also always suggested the suitability of Hypothesis 4.

Discussion

With respect to the results for Hypothesis 1 there naturally arises the question of whether the relatively long reaction times for the reactions with the shortest warning intervals were not due to a refractory phase in the organism in connection with the information signal, in view of the fact that in this case the information signal preceded the actual starting signal only very briefly. This could have a certain effect. So, perhaps, could the sudden change in

attention from one objective to another which is required at the shortest interval, but this influence cannot be decisive, because the difference from the control values with the interval of 1 does not become greater with increasing complexity of the reaction experiment. This would have been expected, according to current findings (Amelang, 1971), rather than the reverse.

The unexpected findings on duration of presentation for the information signal make one revision of the model concept necessary. Apparently noting such a simple content as the specificity of a just perceived signal requires less capacity than would be required for longer participation of this same signal. Consideration of another signal (the starting signal in this case) is affected more, then, by simultaneously occurring processes in the same sense modality than by the short-term storage of the corresponding information. The behavior of the test subject also agrees with that. On directed questioning after termination of the experiment, most subjects stated that the longer exposure durations had not been an advantage for them, because after identifying the information signal they always turned immediately to the matching start signal, independent of how long the former remained presented. /17

But we must also consider that the positive effects of a short exposure of the information signal (or the negative effects of a long exposure) occurred primarily at the moderate intervals 32 and 64. In comparison, either no effect at all or quite the opposite effect appeared with very short or long intervals. This, as mentioned previously, was related with the sequence of the warning intervals. The duration of exposure varied randomly from trial to trial, independent of the sequence of the warning intervals. It may be that this circumstance misled the test subject into a strategy which favored the brief exposure. A further series of experiments was indicated to exclude this factor.

Experiment II

Aside from the above-mentioned viewpoint, this series of experiments attempted to find an explanation for the discrepancy between Merz's findings on interrupted actions and the psychological explanation of the so-called "interruption effect" (that is: shortening of the reaction time for those actions which are supposed to be suppressed or interrupted on the basis of another signal exposed at a time near the starting signal; see Amelang, 1967). In contradiction to the existing model assumptions, Merz was not able to observe a decreasing interruption effect with increasing warning intervals. In our opinion, the following situation was responsible for that: It must be assumed that in experimental series in which opposing instructions are given (that is, one one hand, to react rapidly to the start signal, but to stop the reaction immediately in case an additional interruption signal is given) the test subjects will delay, as it were, for a certain time to await the possible appearance of the interruption signal, which is only exposed separately. The latency times of the unaffected reactions in Merz's first experimental series may be an indication of this. On the basis of such a delay (Hypothesis), the gain in reaction speed expected from information /18 about an alternative might not show up as clearly in experiments where the subject is told of the possibility of the separate exposure of an "opposing" signal as in control experiments without any instruction for interruption. The relatively too large interruption effect in the study by Merz would, in the sense of such an explanation, be caused by the incompletely utilized gain from the warning.

Method

The design of the experiment corresponded in principle to the two-fold choice experiments of Experiment I. Differing from that, trials were prescribed with equally long duration of exposure for the warning signal (16 or 256 hundredths of a second) in blocks successively. Control series without warning could be omitted. Finally, an additional signal was given at random, on the average of every sixth set of signals. This signal, given simultaneously with the start signal, was in the form of a tone of moderate loudness perceived with headphones. In experimental series 1, according to the instructions, this was without significance for the test subjects and their behavior (additional signal, AS). In experimental series 2 the tone was the signal for immediate cessation, suppression or interruption of the intended reactions (interruption signal, IS). Series 1 and 2 were done with the same test subjects, ten psychology students of both sexes. The succession of 1 and 2 varied systematically.

Results

Figure 4 shows the average reaction times from experimental series 1 and 2 as functions of the presentation of the warning signal. The values are derived solely from those trials done without the tone.

We can see two results: As predicted, the reaction times (for the unaffected reactions, i. e., those without the additional tone) from experimental series 2 (the IS experiment) are higher than those from series 1 (the AS experiment). Furthermore, as also expected, the decrease of the values was less strong in 2 than in 1. These effects are statistically significant (three-fold variance analysis, factor: "Experiment 1/Experiment 2" $F = 38.33$; $df = 1/9$; interaction

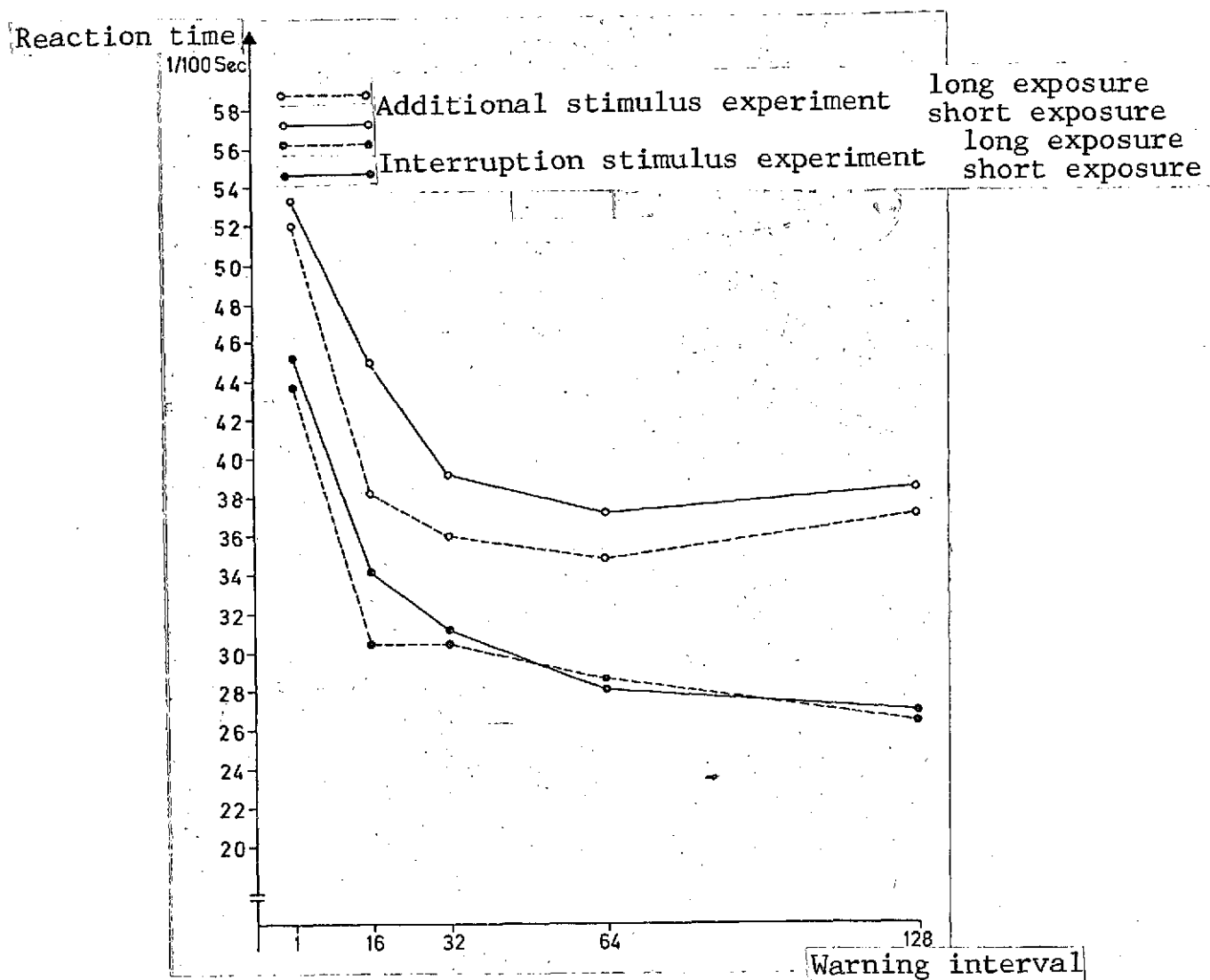


Figure 4. Average reaction times (in hundredths of a second) from experimental series 1 and 2 as functions of the length of the warning interval and duration of warning signal exposure. The values refer solely to those trials done without presentation of the additional or interruption signal.

Experiment 1/Experiment 2 x Interval, $F = 6.41$; $df = 4/36$).

The difference in favor of the short, as opposed to the long, exposure for the information signal is also significant ($F = 11.44$; $df = 1/9$). Numerically more distinct figures,

to be sure, are derived only from Series 2 (the interaction between experimental series and exposure duration is significant, certainly).

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Figure 5 shows the reaction times for the uninfluenced reaction times in comparison with those from experiments with the additional signal. In series 1 the values for the reactions with supplementary signal are slightly below those for the uninfluenced reactions, with one exception (difference not significant; three-fold variance analysis with the factors warning interval, exposure duration and with/without supplementary signal). In series 2 the numerical difference is considerably greater, and it remains about the same for the various warning intervals. No confirmation with respect to random influence was done because only part of the test subjects were still able to suppress the intended reaction (and correspondingly provided reaction times). For these latter subjects, the values for their uninfluenced reactions are also plotted (dotted line in Figure 5). As apparent, these values are below those of the whole group. As known from previous experiments, these are primarily the test subjects which react comparatively rapidly (= the ones which do not delay) which could not suppress the intended reaction, because it occurred too soon. Considering only this subgroup, furthermore, we can detect a certain convergence of the functions for uninfluenced and interrupted reactions with longer warning intervals (if we ignore the interval 128, for which there were only 5 measurements, in comparison to 11 measurements for the interval 64, 8 for 32, and 11 for 16). This agrees with the model concepts previously mentioned.

Finally, it is remarkable that the reaction times for the interrupted reactions are at best as short as the reaction times from experiments with the same but unspecific supplementary signal. This will have to be considered more in further studies.

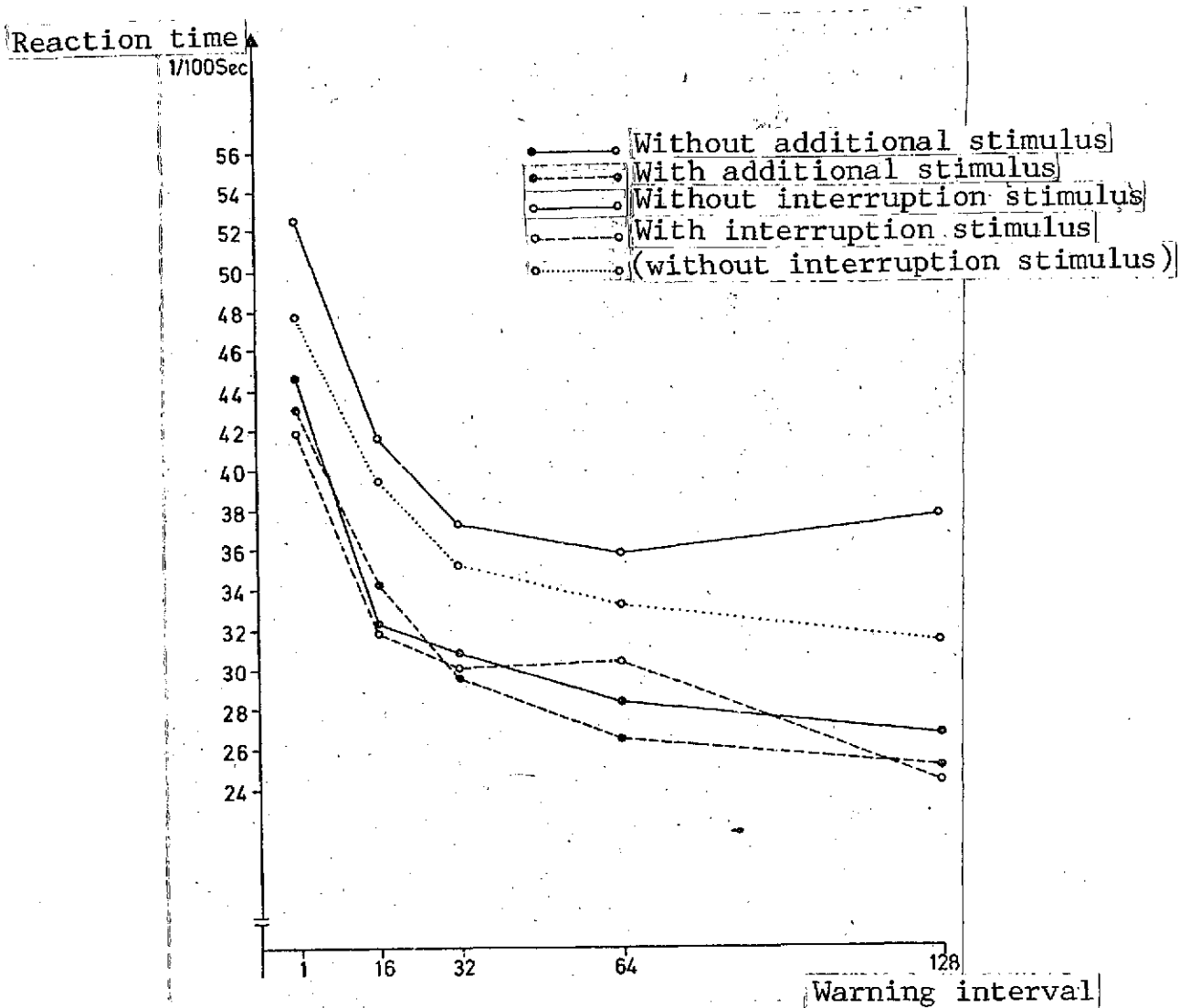


Figure 5. Mean reaction times from experimental series 1 and 2, with averaging over both stages of exposure duration for the information signal. Classed into those reactions in which an additional signal or an interruption signal (AS or IS) is given simultaneously with the actual starting signal. Dotted Line: reaction times of uninfluenced reactions in those test subjects who provided values for reactions with (and in spite of) interruption signals.

Concluding Remarks

The observations presented indicate that warning about choice reactions does not necessarily accelerate the reaction finally given in every case. If the information is not early enough, that is, not at least 10 to 15 hundredths of a second before the actual start signal, not only is there no improvement in the reaction rate, but it is actually slowed down.

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This is apparently because the fact of warning is an additional problem which must be processed. This is also expressed in the fact that there are still reliable differences in the reaction time as a function of the information content of the warning, even when the warning signal precedes the actual start signal by a relatively long time. This information must be stored up to the "Go" signal, and the holding processes interfere with the quick performance of the specified action.

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It is also known from other studies that interferences of this nature are especially strong immediately after exposure of an attention problem, and become weaker with increasing time from their presentation. In experiments by Moog and Mührer (1971), this is expressed in the particularly distinct delay in those reactions which must be performed shortly after exposure of a memory problem. The mental consolidation processes which can be assumed as the cause of this effect simultaneously provide an explanation for why here, as in the experiments of Merz, the time separation between the information signal and the reaction did not remain constant at short warning intervals (see Merz, pages 643 to 645).

Furthermore, the value of a warning for problems with practical significance is reduced, or even placed in question, by the fact that even a few trap experiments were sufficient to produce a distinct and quite general slowing of the reaction

rate. In situations outside the laboratory the portion of "empty" warnings, that is, of indications with no matching event, will presumably be even greater, so that the reaction to an event which actually occurs, with warning in good time, would be seriously delayed.

The circumstance that the function of the reaction rate for warned reactions is negatively accelerated even in its initial course (short intervals) could be important for the theory of the initiation of simple actions. This situation suggests the conjecture that the process of information reduction in conventional choice reaction experiments does not occur in equally large steps on exposure of one of several signals, but, rather, that in the course of an iteration process the large differences are eliminated first, and then increasingly smaller ones. Certainly the viewpoint on the role of memory, mentioned above, which is conjectured to be different for the various warning intervals, agrees with such an interpretation.

These memory processes also become relevant to the exposure duration of the information signal. Even though a shorter duration of exposure for these signals leads to generally shorter reaction times, in contrast to what would be expected, there are some bases for the usefulness of Hypothesis (3) which we formulated initially: At the longest warning interval (choice experiment) the warning times after long exposure are always below those for only short presentation of the warning. Even in the simple reaction experiment the increase of the corresponding times from interval 64 to 128 is greater than for the brief warning signals. Admittedly, the very much more distinct difference in the opposite sense for intervals 32 and 64 does not fit into this concept. Here, after the questionable effect also appeared in Experiment II, we must ask whether the turning off of the warning signal does not contain an indication for the

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test subject to await the start signal more intensely. Perhaps, too, the change in the basic stimulus pattern leads to a general activation. This, to be sure, can be only of minor intensity and short duration, as the effect does not occur any more at longer intervals, or is covered up by the postulated behavior processes.

Summary

In complex reaction-time experiments, an additional stimulus was given before the actual stimulus. The additional stimulus informed the subject which of the actual stimuli would appear in a short time. In different experiments, the additional stimulus was shown for 0.16 sec. or 2.56 sec., and the interval between the additional stimulus and the actual stimulus lasted for 0.01 sec., 0.16 sec., 0.32 sec., 0.64 sec., or 1.28 sec. The sequence of presentation of stimuli with different intervals was also varied. Simple reaction-time experiments and complex reaction-time experiments without additional stimulus were conducted as control experiments.

Reaction time decreased with increase in the interval between the additional stimulus and the actual stimulus in complex reaction time experiments. The reaction time in these experiments was, however, never shorter than that in the simple reaction time experiments. Longer exposures of the additional stimulus produced longer reaction times.

In another set of experiments, beside the additional stimulus before the actual stimulus, a neutral stimulus or a stimulus giving a signal to interrupt the reaction was given simultaneously with the actual stimulus. Reaction time was shorter when the stimulus signaling interruption was given. Reaction time was prolonged in experiments without the interruption signal because the subjects continued to wait for the interruption signal.

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